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FABRICS EMPLOYING BINDER/TOP INTERCHANGING YARN PAIRS

FIELD OF THE INVENTION

The present invention relates to fabrics employed in web forming equipment, such as papermaking and non-woven web forming equipment. More particularly, the preferred fabrics of this invention are employed as forming fabrics in web forming equipment; most preferably in papermaking machines.

BACKGROUND OF THE INVENTION

Paper is conventionally manufactured by conveying a paper furnish, usually consisting of an initial slurry of cellulosic fibres, on a forming fabric or between two forming fabrics in a forming section, the nascent sheet then being passed through a pressing section and ultimately through a drying section of a papermaking machine. In the case of standard tissue paper machines, the paper web is transferred from the press fabric to a Yankee dryer cylinder and then creped.

Paper machine clothing is essentially employed to carry the paper web through these various stages of the papermaking machine. In the forming section the fibrous furnish is wet-laid onto a moving forming wire and water is encouraged to drain from it by means of suction boxes and foils. The paper web is then transferred to a press fabric that conveys it through the pressing section, where it usually passes through a series of pressure nips formed by rotating cylindrical press rolls. Water is squeezed from the paper web and into the press fabric as the web and fabric pass through the nip together. In the final stage, the paper web is transferred either to a Yankee dryer, in the case of tissue paper manufacture, or to a set of dryer cylinders upon which, aided by the clamping action of the dryer fabric, the majority of the remaining water is evaporated.

So called "triple layer" paper machine fabrics are well known in the art. These generally comprise paper side and machine side warp and weft yarn systems, which are bound together by additional binder yarns whose sole

function is to join the two fabric layers. Such structures have caused sheet marking due to binder activity on the paper side fabric. More recently triple-layer fabrics have become available where interchanging pairs of yarns bind the two fabric layers together but also weave as part of the paper side weave to reduce sheet marking.

Ward US 5,437,315 discloses a triple-layer fabric with plain weave surface wherein, within the fabric weave repeat, each binder weft interchanges with a matching top weft once over a single paper side warp. The interchanging is such that when the binder weft appears in the paper side surface to bind with a paper side warp yam the paper side weft yarn drops out of the paper side surface and floats between the fabric layers for a length of three paper side warp yarns. The potential dewatering restriction caused by a binder weft interlacing with a paper side warp alongside a paper side weft knuckle is, therefore, addressed by '315. However, because there are minimal binder and warp interlacings in the embodiment of '315 due to the choice of weave pattern and MD yarns per unit width, all of the binder yarns feature long lengths of unbound yarn floating between the paper side and wear side fabrics such that fabric thickness, water carry and stability may be problematic. Furthermore the low level of binder-warp interlacings in each layer, and the preference for polyester binder material, fails to address delamination issues.

EU 1,000,197A and divisional patent EU 1,158,090A both disclose triple layer fabric in which the paper side weave is obtained by the interweaving of paper side machine direction (MD) or warp yarns with both paper side weft yarns and interchanging pairs of weft yarns. In addition to each interchanging weft pair providing a single continuous weft path in the paper side fabric, each pair member also acts to bind the paper side and wear side fabrics together.

While commercial embodiments according to '197 and divisional patent '090 have been found to give some benefits such fabrics utilised the same MD

yarn diameter and yarns per unit width as '315, and thus were also found to possess high thickness such that water carried within the fabric void space may, near the end of the paper machine's sheet forming zone, rewet the paper sheet resulting in decreased machine efficiency. EU 1,273,698A seeks to resolve this issue for the same weave patterns disclosed in '197/090 by utilising greater numbers of thinner MD and CD yarns than were used hitherto such that thinner structures with less void space are provided. While this approach is helpful in resolving the so-called "sheet rewet" issue it creates a new problem in that the finer fabric has reduced CD bending stiffness and consequently the less stable fabric has a decreased ability to minimise sheet basis weight profiles.

The problem of fabric bending stiffness in a triple-layer fabric containing interchanging weft yarn pairs was addressed to some extent by Kufferath WO 02/14601, wherein Figure 3 featured interchanging paper side weft pairs whose members, when not weaving over and under the paper side warp yarns to provide a single continuous weft path in plain weave pattern, were positioned between the fabric layers to provide a straight section of yarn bound at either end with paper side warp yarns. These stiffening sections of yarn contribute to enhanced fabric CD bending stiffness. Neither member of the interchanging top weft pair made any interlacing with wear side warp yarns to bind paper side and wear side fabrics together. Other pairs of interchanging wefts present in the same embodiment were disposed as binder-top weft pairs i.e. a paper side or top weft interchanged with a binder weft to provide a single continuous paper side weft path. The binder members of the binder-top weft pairs featured in '601 interlace with a single wear side fabric warp yarn, in other words "binder–top" weft pairs are provided wherein the top weft member by virtue of its straight section helps to stiffen the fabric and wherein the binder member joins the fabric layers. Although fabric CD bending stiffness is enhanced there is a significantly reduced frequency of bindings of the fabric layers such that resistance to delamination decreases compared with the embodiments of '197/'090. Commercial fabric from the applicants of '601, sold under the brand name of

Geoflex X-325 has been observed in which the interchanging top weft pairs have been replaced by interchanging binder-top weft pairs such that all interchanging weft pairs are of the binder-top type. These fabrics have been found to contain relatively coarse, thick, warp and weft yarns such that fabric has a considerable thickness and a high potential to rewet the sheet. Furthermore there is minimal interlacing of binders with the wear side fabric layer such that fabric layer shifting and delamination issues are not addressed.

OBJECTS OF THE INVENTION

It is an object of the invention to provide triple-layer fabrics with enhanced cross-machine-direction stiffness.

It is a further object of the invention to provide a triple-layer fabric having a desirably low void volume and water carry potential.

It is a further object of this invention to provide a triple-layer fabric with enhanced fabric delamination resistance between a paper side and wear side layer of the fabric.

It is a more specific object of the invention to provide a relatively fine and thin fabric with reduced void volume and water carry potential.

It is another object of the invention to provide a triple layer fabric with excellent wear side abrasion resistance.

It is a more specific object of this invention to provide a triple layer fabric having a desirably low void volume and water carry potential in combination with good delamination resistance and CD bending stiffness.

SUMMARY OF THE INVENTION

The above and other objects of this invention are obtained in "binder-top" composite fabrics. The meaning of "binder-top" will be explained in detail later herein.

In accordance with a preferred embodiment of this invention a multi-layer forming fabric has a paper side warp layer and a machine side warp layer, the fabric comprising at least one set of paper side wefts, at least one set of machine side wefts and at least one pair of interchanging weft yarns, the members of each interchanging weft pair together forming one continuous weft path on the paper side and all of said interchanging weft pair members interweaving with at least one paper side warp and, in at least one interchanging weft pair, only one of the members interweaving with at least one machine side warp. In other words, at least one interchanging weft yarn pair includes one weft yarn that, within each weave repeat, forms part of the continuous weave pattern in the paper side layer, and then moves out of the paper side layer adjacent one side of a paper side warp transition yarn to float between the paper side and wear side layers before re-entering the paper side layer. This latter weft yarn does not bind to any warp yarns in the wear side layer and is the "top" weft yarn of the binder-top interchanging yarn pairs. The other yarn of the interchanging top weft yarn-binder yarn pair is a binder yarn that moves into the paper side layer on the side of the paper side warp transition yarn opposite the side where the interchanging top weft yarn of the pair moves out of the paper side layer to thereby maintain the continuity of the continuous weave pattern in the paper side layer in the location

overlying the region were the interchanging top weft yarn floats between the paper side and wear side layers. The binder yarn of the pair then moves out of the paper side layer on the side of a second paper side warp transition yarn opposite the side where the top weft yarn re-enters the paper side layer, and, in the region underlying the segment where the interchanging weft yarn binds to the warp yarns of the paper side layer, the interchanging binder yarn binds to at least one warp yarn of the wear side layer to bind together the paper side and wear side layers. In accordance with the broadest aspect of this invention the fabric is not required to be a forming fabric.

In accordance with another aspect of this invention the paper side layer of the fabric comprises only paper side warp yarns and interchanging weft yarn pairs, of which at least one pair comprises one binder member and one top weft member, such that there are no additional top weft yarns present. In other words interchanging yarn pairs form all of the continuous weft paths in the paper side layer and at least one of the interchanging yarn pairs is a top weft-binder yarn pair to also bind to bottom warp yarns to hold together the paper side and wear side layers.

As used throughout this application, "intrinsic binder yarn/ top weft yarn pairs," or simply "binder-top" pairs, means a pair of interchanging yarns wherein one yarn of the pair, namely the binder yarn, forms the weft path in the paper side surface of the paper side layer in a first segment of each repeat of the weave pattern and then drops down to encircle at least one warp yarn in the machine side layer in a region underlying an adjacent second segment in the paper side layer. The intrinsic top weft yarn of the binder-top pair forms the weft path in a second segment in the paper side layer within each repeat of the weave pattern that is not occupied by the binder yarn of the pair, and then drops out of the paper side layer to float between the paper side layer and machine side layer in the first segment within each repeat of the weave pattern, without in any way binding the paper side layer to the machine side layer within the weave repeat.

The resulting float, if it extends between two or more adjacent pairs of top and bottom warp yarns, is defined herein as a stiffening section. The binder yarn of the binder-top pair may also provide stiffening sections by interlacing with spaced apart wear side fabric MD yarns and floating between at least two adjacent pairs of top and bottom warp yarns between such interlacings. A "top weft yarn/binder yarn pair" is illustrated in Fig. 2(b) of International Publication No. WO 02/14601, the subject matter of which is incorporated herein by reference.

Reference throughout this application to "intrinsic interchanging weft binder yarns" or "interchanging weft binder yarns" means paired yarns, each of which forms a part of the weave structure in at least the paper side layer of the composite fabric and also binds the paper side layer and machine side layer together. Thus, each intrinsic weft binder yarn of each pair of first and second intrinsic weft binder yarns provides two functions within each repeat of the weave pattern. One function is to contribute to the weave structure of the paper side surface of the paper side layer, and the second function is to bind together the paper side layer and the machine side layer.

In accordance with the more preferred embodiments of this invention at least 50% of the pairs of intrinsic interchanging yarns, and most preferably 100% of such pairs, are intrinsic, interchanging binder-top yarn pairs providing a minimum of 2 segments within each weave repeat, as described above. However, it is within the scope of this invention to also include within the fabrics other types of intrinsic interchanging weft yarn pairs other than binder-top yarn pairs, such as "intrinsic binder yarn/binder yarn pairs" (hereinafter binder-binder) in combination with the plurality of intrinsic, interchanging binder-top yarn pairs. It also is within the scope of the broadest aspects of this invention to provide intrinsic, interchanging binder-top yarn pairs that constitute less than 50% of the pairs of intrinsic interchanging yarns.

In accordance with certain preferred embodiments of this invention the

ratio of paper side to wear side warp yarn diameter is in excess of 0.75 such that when relatively fine paper side MD yarns are used the fabric thickness is suitably low.

In accordance with certain preferred embodiments of this invention the cover factor of the paper side warp yarns/cm unit width (calculated by multiplying yarn diameter by the number of yarns/cm by 10) is in excess of 40.0% such that when relatively fine paper side MD yarns are used the initial drainage through the fabric may be adequately controlled.

In accordance with certain preferred embodiments of this invention the paper side and wear side warp diameter combinations are selected from the group of: 0.11mm paper side and up to 0.15mm wear side; 0.12mm paper side and up to 0.17mm wear side; 0.13mm paper side and up to 0.19mm wear side; 0.14mm paper side and up to 0.19mm wear side; 0.15mm paper side and up to 0.20mm wear side; & 0.16mm paper side and up to 0.22mm wear side.

In accordance with certain preferred embodiments the paper side MD yarns/cm unit width when using 0.12mm paper side MD yarns is in the region of 35 to 40 yarns/cm; when using 0.13mm paper side MD yarns is in the region of 30 to 35 yarns/cm; when using 0.14mm paper side MD yarns is in the region of 30 to 35 yarns/cm; when using 0.15mm paper side MD yarns is in the region of 28 to 33 yarns/cm and when using 0.16mm paper side MD yarns is in the region of 26 to 33 yarns/cm.

BRIEF DESCRIPTION OF THE DRAWINGS

Details of various preferred embodiments of the invention will now be described in connection with the following drawings, wherein:

Fig. 1 is a cross sectional view of a 20 shaft, triple-layer fabric of the prior art showing the weave paths of 3 paper side wefts, 3 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, said prior art fabric being shown for comparative purposes;

Fig. 2 is a cross sectional view of a 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 3 is a cross sectional view of another 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 4 is a cross sectional view of a third 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of 3 paper side wefts, 3 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full

weave repeat comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 5 is a cross sectional view of a fourth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave; the full weave repeat comprising 20 paper side wefts, 20 wear side wefts, and, 20 pairs of interchanging binder-top weft yarns;

Fig. 6 is a cross sectional view of a fifth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 7 is a cross sectional view of a sixth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 8 is a cross sectional view of a seventh 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 9 is a cross sectional view of an eighth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current

invention showing the weave paths of 3 paper side wefts, 3 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 10 is a cross sectional view of a ninth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of 3 paper side wefts, 3 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 11 is a cross sectional view of a tenth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 12 is a cross sectional view of an eleventh 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of 3 paper side wefts, 3 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 10 paper side wefts, 10 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 13 is a cross sectional view of a twelfth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of one to one, of the current invention showing the weave paths of 3 paper side wefts, 5 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 10 paper side wefts, 20 wear side wefts, and, 10 pairs of interchanging binder-top weft yarns;

Fig. 14 is a cross sectional view of a thirteenth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of three to two, of the current invention showing the weave paths of 4 paper side wefts, 4 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 40 paper side wefts, 40 wear side wefts, and, 20 pairs of interchanging binder-top weft yarns;

Fig. 15 is a cross sectional view of another embodiment of the invention in the form of a 28 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of all CD yarns in a full repeat of the total fabric weave comprising 14 paper side wefts, 14 wear side wefts, and, 14 pairs of interchanging binder-top weft yarns;

Fig. 16 is a cross sectional view of a 32 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two-to-one, of the current invention showing the weave paths of 3 paper side wefts, 3 wear side wefts, and, 2 pairs of interchanging binder-top weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 16 paper side wefts, 16 wear side wefts, and, 16 pairs of interchanging binder-top weft yarns;

Fig. 17 is a cross sectional view of a fourteenth 20 shaft, triple-layer fabric, with effective paper side to wear side CD ratio of two to one, of the current invention showing the weave paths of 5 paper side wefts, 5 wear side wefts, 2 pairs of interchanging binder-top weft yarns, and 2 pairs of interchanging binder-binder weft yarns in a partial repeat of the fabric weave, the full weave repeat comprising 20 paper side wefts, 20 wear side wefts, 10 pairs of interchanging binder-top weft yarns; and 10 pairs of interchanging binder-binder weft yarns;

Fig. 18 is a cross sectional view of one pair of interchanging binder-top weft yarns from a fifteenth 20 shaft triple-layer fabric of the current invention;

Fig. 19 is a cross sectional view of one pair of interchanging binder-top weft yarns from a 24 shaft triple-layer fabric of the current invention;

Fig. 20 is a cross sectional view of one pair of interchanging binder-top weft yarns from a sixteenth 20 shaft triple-layer fabric of the current invention; and

Fig. 21 is a summary chart of various features of the embodiments of this invention shown in Figs. 1-20.

DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

In describing various embodiments of the invention reference may be made to a number of features, which are defined below, prior to describing the various embodiments of this invention.

a) Interchanging Weft Yarn Segments

The two members, or yarns, of an interchanging weft pair interchange to provide one continuous weft path on the paper side fabric, or layer and one or both of the pair may also bind to wear side fabric MD yarn(s). Each part of the paper side weft path made by one of the pair members is defined as a "segment." The segment length is defined as the number of paper side layer warps in an adjacent preceding transitional region plus the paper side warps with which the interchanging yarn weaves under or over before entering the next transitional region. In the fabrics of the invention the yarns of each interchanging yarn pair typically transition, or move in/out of the paper side layer alongside opposite sides of common paper side warp yarn(s), such that the two members of the interchanging pair actually cross each other beneath such warp yarn(s). The common paper side warp yarn(s) is (are) referred to as a "transitional" (warp) yarn or yarns. In the most preferred embodiments the common paper side warp yarn is a single, top warp yarn, and the yarn of an interchanging yarn pair that is weaving with the top warp yarns in the paper side layer upstream of that transitional warp yarn will move out of the paper side layer adjacent the upstream side of the transitional warp yarn and the other yarn of the pair will move into the paper side layer adjacent the other, or downstream side of the transitional warp yarn. The two interchanging yarns cross each other in a region generally

underlying the transitional warp yarn. The upper surface of each such transitional warp yarn may be referred to as a transition point, even though the interchanging weft pair transition (i.e., crossover) occurs under these yarns. In instances where the interchanging yarn pair transitions between contiguous paper side warp yarns, instead of under one or more paper side warp yarns, then the transition point is considered to be located equidistant to both of the contiguous paper side warp yarns. It should also be noted that the further terms "interchange point(s)" and "interchange warp(s)" as used within this application have identical meanings to "transition point(s)" and "transitional warp(s)" respectively. It also should be noted that such interchanging points and interchanging warps are included in prior art structures, such as the structures disclosed in the earlier identified Ward '197 patent, which already has been fully incorporated by reference herein.

As with the weave repeat of the prior art fabrics, embodiments shown herein repeat after two interchanging yarn segments. When a pair of first and second intrinsic, interchanging weft yarns includes two segments in the paper side layer within each repeat of the weave pattern, each yarn of that pair interchanges position into and out of the paper side layer two times within each such repeat. That is, a first yarn of the interchanging yarn pair is in the paper side layer in a first segment to form part of the continuous top weave pattern in each repeat; is beneath the paper side layer in a region underlying a second segment where it may also bind to one or more bottom warp yarns or alternatively it may remain between the fabric layers, and then is in the paper side layer in a first segment of a new repeat of the weave pattern. The other, or second, yarn of the interchanging yarn pair is in the paper side layer in the second segment to cooperate with the first yarn of the pair to complete the continuous top weave pattern in each repeat of the weave pattern; is in the machine side layer underlying a first segment of the paper side layer to bind to one or more bottom warp yarns in a region underlying such first segment, and

then is in the paper side layer in a second segment of an adjacent repeat of the weave pattern.

It is also possible to make multi-segment structures with 4 or more segments, as disclosed in co-pending provisional patent application no. 60/477,376, filed on June 10, 2003, and incorporated herein by reference and attached hereto as Exhibit A.

b) Binder Internal Float Length

The binder yarn in each interchanging pair of yarns employed in multi-layer fabrics of this invention moves between one fabric layer and the other. Thus, at some stage, after binding with an MD yarn of a first fabric layer the binder yarn then floats between warp yarns of the respective fabric layers before entering the second fabric layer to bind with an MD yarn in the second layer. The distance between leaving the first fabric layer and entering the second fabric layer is specified in terms of pairs of MD yarns and is the binder's internal float length (or simply "float length") e.g., for a binder float length equal to one, the binder passes below a warp of the upper fabric layer and above a warp of the lower fabric layer with both of said warp yarns being aligned and constituting one pair of MD yarns. Embodiments of this invention illustrated herein are fabrics with 1:1 ratio of top-to-bottom MD yarns. However, within the broadest scope of this invention MD ratios other than 1:1 can be employed, for example, 3:2 or 2:1. In such cases the binder will float between full or partial groups of warp yarns instead of between pairs.

Excessively long binder float lengths are not preferred because they may create a relatively large vertical distance, or gap, inside the fabric, i.e. between the paper side and machine side layers, such that the structure may carry and retain more water than desired during sheet formation. The carried water, in turn, may be discharged onto the sheet being formed at the end of the forming

section, thus undesirably increasing the sheet moisture content. Preferred embodiments of the invention have binder float lengths of between 1 and 3.

c) Interchanging Yarn Stiffening Section

Each interchanging yarn may, after interlacing around a warp yarn on the outside of either fabric layer, return to and remain inside the fabric, i.e., between the two fabric layers, before making a further interlacing with another warp yarn of the same layer. In the paper side layer of certain fabrics of this invention the interchanging yarn pair provides long external CD orientated yarn floats while in other fabrics of the invention the interchanging yarns weave in a plain weave, i.e., such that they weave over and under single adjacent warp yarns of the paper side layer. However, an interchanging yarn stiffening section within the fabrics of this invention requires the interchanging yarn to remain inside the fabric for two or more adjacent warp yarns and to be bound on each end of the stiffening section with a warp yarn of the same fabric layer. By this means a straight section of yarn is provided to enhance fabric cross-machine-direction (CD) bending resistance. Furthermore, it may also be possible to reduce the internal float length of the binder yarn by creating a stiffening section through interlacing with wear side fabric MD yarns to ensure a minimal "layer gap" between the respective fabric layers. These features of the invention are desirable to minimize undesired sheet moisture content and profiles therein, respectively, and will be described in detail hereinafter with respect to various embodiments of this invention.

d) Locked/unlocked Binder

This refers to the binder members of the interchanging weft pairs and more particularly to the binder knuckle positions on the wear side layer in relation to the interlacings of adjacent wear side fabric warp and weft (non-interchanging) yarns. Where a binder of an interchanging yarn pair makes a knuckle under a

yarn, or contiguous yarns, of the wear side layer and said knuckle is bordered on both sides by the adjacent warp yarns of the wear side layer interlacing with non-interchanging bottom weft yarns then said binder knuckle is classified as "locked" into position because the adjacent yarns will not allow that binder knuckle to move from its position, either in fabric manufacture or in end use of the fabric. Where the binder knuckle is not so bordered on both sides by MD-CD interlacings then it is classified as "unlocked." Both unlocked and locked binder knuckle positions are included in embodiments of this invention.

In order to better understand the present invention, a prior art, 20 shaft fabric disclosed in Ward U.S. Patent No. 5,437,315 will be briefly described in connection with Fig. 1.

As can be seen in Fig. 1, several weft paths from the prior art fabric according to the Ward '315 patent are shown. Specifically, Fig 1 shows three, non-interchanging top weft yarns T1, T2 and T3; three, non-interchanging bottom weft yarns B1, B2 and B3 and two pairs 40 and 42 of interchanging top weft/binder yarns. The pair 40 includes top weft yarn I1 (shown in solid line) and binder yarn I2 (shown in dotted line). The pair 42 includes top weft yarn I3 (shown in sold line) and binder yarn I4 (shown in dotted line).

It is clear from Figure 1 that the binder weft yarn I4 of the interchanging pair 42 has relatively long internal paths between the paper side and wear side layers. Specifically, in each weave repeat, binder weft yarn I4 floats between four adjacent top and bottom warp pairs 19-20, 1-2, 3-4 and 5-6 before binding to top warp yarn 7, and then floats between three adjacent top and bottom warp pairs , 9-10, 11-12 and 13-14 before binding to adjacent bottom warp yarns 16 and 18. Long internal binder yarn paths, or floats, are known to contribute to undesirably high fabric thickness and also can move quite freely, thereby resulting in significant binder wear due to contact of the weft yarn with the inside of the two fabric layers as the composite structure travels around the paper

machine.

The preferred embodiments of '315 also use a relatively low number of MD yarns in each layer such that distances between paper side yarns, and thus binder float length, are further extended.

Referring to Fig. 2, a first preferred embodiment of this invention is shown. This fabric is a 20 shaft, triple-layer fabric containing ten (10) pairs of interchanging binder-top weft yarns 40a, 42a, 44a . . . 58a. Which alternate with ten (10) pairs of non-interchanging top weft yarns and bottom weft yarns T1-B1, T2-B2, T3-B3 . . . T10-B10. Each of the pairs of interchanging binder-top weft yarns interchange to provide two paper side segments. The binder yarn I1 (dotted line) of the first pair 40a of interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp yarns 17, 19, 1, 3, 5 and 7, and binds in a locked position, to a single bottom warp yarn 14 in regions underlying said second segments. The top weft yarn I2 (solid line) of said first interchanging binder-top weft yarn pairs 40a provides a second paper side segment, but of 4 paper side warp yarns 9, 11, 13 and 15, and floats between the paper side and wear side fabrics to provide a stiffening section of 7 warp pairs in the region underlying said first segments, i.e., 17-18, 19-20, 1-2, 3-4, 5-6, 7-8 and 9-10. Alternate pairs 40a, 44a, 48a, 52a and 56a are of the same general arrangement as pair 40a, having the same paper side segment lengths, provided respectively by binder and top members, as described in connection with interchanging pair 40a and the binder yarn of each such pair binding to a single wear side warp yarn in a locked position, as can be seen in Fig. 1.

Alternate pairs of binder-top weft yarns 42a, 46a, 50a, 54a and 58a are of the same general arrangement, as will be described in detail with respect to pair 42a. In pair 42a, binder yarn I3 (solid line) provides the shorter paper side segment of 4 paper side warp yarns 13, 15, 17 and 19 and binds in a locked position, to single wear side warp yarn 8 in the region underlying the longer

segment of 6 paper side warp yarns 1, 3, 5, 7, 9 and 11 provided by the top weft yarn I4 (dotted line). In said second alternate binder-top pairs 42a, 46a, 50a, 54a and 58a the stiffening section length provided by the top weft yarn of the pair is reduced to 5 pairs of warp yarns, e.g., 13-14, 15-16, 17-18, 19-20 and 1-2 provided by I4 of pair 42a.

Thus, the fabric illustrated in Fig. 2 has a reversing insertion order of the long and short segments between adjacent interchanging bind-top yarn pairs. That is, in one of the pairs, e.g., 40a, the binder yarn I1 (dotted line) is inserted prior to top weft yarn I2 and provides three (3) paper side knuckles over top warp yarns 19, 3 and 7 in the paper side segment. However, in the adjacent pair 42a, the yarn that provides only 2 knuckles in the paper side layer is inserted first; which is binder yarn I3 (solid line) forming 2 knuckles over top warp yarns 15 and 19 in the paper side segment. This reversing insertion order is identified by the numbers to the left of the interchanging yarns of each pair, which numbers specify the number of knuckles formed by the specific interchanging yarns. Thus, the numbers "3 – 2" to the left of the interchanging pairs 40a, 44a, 48a, 52a and 56a means that the yarn of the pair that forms 3 paper side knuckles is inserted first, and the yarn of the pair that forms 2 paper side knuckles is inserted second. In binder pairs 42a, 46a, 50a, 54a and 58a the yarn of the pair that forms 2 paper side knuckles is inserted first, and the yarn of the pair that forms 3 paper side knuckles is inserted second. In each alternative pair 40a, 44a, 48a, 52a and 56a, the binder yarn of the pair forms the 3 paper side knuckles and the top weft yarn of the pair forms the 2 paper side knuckles within their respective top, or paper side segments. Note that in all 10 interchanging pairs in this embodiment the binder member is inserted first. The reversing refers to the paper side segment lengths – not the yarn function. Reversing of segments, or insertion order of binder-top members, or both segments and members is not a requirement of the invention but may be utilised for any embodiment of the invention if desired for example to break up patterns caused by alignment of paper side interchanging yarn knuckles or wear side binder knuckles.

Referring to Fig. 3, another embodiment of this invention is shown. The fabric of this embodiment is a 20 shaft, triple-layer fabric containing pairs of interchanging binder-top weft yarns that interchange to provide two paper side segments, as in the previously described embodiment shown in Fig. 2. The binder yarn of all said pairs of interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp yarns, and binds in a locked position, to a single bottom warp yarn in regions underlying said second segments. For example, the binder yarn I1 (dotted line) of the interchanging binder-top weft pair 40b provides a first segment with paper side warp yarns 17, 19, 1, 3, 5 and 7, and the binds in a locked position to single bottom warp yarn 14. As can be seen from Fig. 3, this same relationship exists for the binder yarns of each of the interchanging pairs 40b, 42b, 44b . . . 58b.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but always of 4 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 7 warp pairs in the region underlying said first segments such that the stiffening effect is increased by comparison to the first embodiment. For example, the top weft yarn I2 (solid line) of the binder pair 40b provides a second paper side segment with top warp yarns 9, 11, 13 and 15, and then floats between warp pairs 17-18, 19-20, 1-2, 3-4, 5-6, 7-8 and 9-10. As can be seen in Fig. 3 this same relationship exist for the top weft yarn in each of the interchanging yarn pairs 40b, 42b, 44b . . . 58b.

The fabric disclosed in Fig. 3 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms three paper side knuckles in the paper side segment alternates between being inserted first and second in each respective pair 40b, 42b, 44b . . .58b. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms two knuckles in the paper side segment, is inserted second, and vice versa.

Table 1 shows some test data for a sample fabric according to Figure 3 compared with the weave according to the prior art Ward '197 patent.

Table 1

	Ward '197	Fig 3
MD Dia PS/WS(mm)	0.12/0.15	0.12/0.15
CD Dia PS/WS(mm)	0.13/0.20	0.13/0.20
Interchanging pair Dia (mm)	0.13	0.13
MD/CD Yarns/cm	76.4/59.3	76.3/59.3
Thickness (mm)	0.70	0.70
Void volume (cm^3/m^2)	443	446
CD Bend Stiff Ratio	100	119
PS Support Points ($/cm^2$)	1509	1508

Table 1 shows the only significant difference is the enhanced CD bend stiffness of the invention, i.e., an almost 20% increase. Both sample fabrics utilised 0.12/0.15mm paper side and wear side MD yarn diameter, respectively at approximately 76 MD/cm. CD and binder diameter were 0.13mm and other suitable diameters include 0.10mm, 0,11mm, and 0.12mm. The utilisation of relatively high MD yarns/cm allows the weave to repeat in a very small area such that a relatively high number of binding points can be obtained to enhance delamination resistance.

Referring to Fig. 4, a partial representation of another embodiment of a fabric in accordance with this invention is shown. This latter fabric, like the earlier described embodiments, is a 20 shaft, triple-layer fabric containing pairs of interchanging binder-top weft yarns, e.g., 40c, 42c, which interchange to provide two paper side segments, and with each interchanging pair alternating with a pair of non-interchanging top weft yarns and bottom weft yarns, e.g., T1-B1, T2-B2 and T3-B3.. The binder yarn of all said pairs of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns, and binds, in a locked position, to a single bottom warp yarn in regions underlying said second segments. For example, the binder yarn I2 (solid line) of interchanging pair 40c provides a paper side segment with top warp yarns 9, 11, 13 and 15, and then binds, in a locked position, to bottom warp yarn 4. This same relationship exists for binder yarn I3 of interchanging pair 42c, as well as for all of the remaining interchanging pairs.

The top weft yarn of each of said interchanging binder-top weft yarn pairs provides a second paper side segment, but always of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments such that the stiffening effect is decreased by comparison to the previous embodiment. For example, top weft yarn I1 (dotted line) of the interchanging pair 40c provides a second paper side segment with paper side warp yarns 17, 19, 1, 3, 5 and 7, and

then floats between the five warp pairs 9-10, 11-12, 13-14, 15-16 and 17-18. This same relationship exists for top weft yarn I4 of the interchanging pair 42c, as well as for all of the remaining interchanging pairs.

As in the fabric disclosed in Fig. 3, the fabric disclosed in Fig. 4 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms two paper side knuckles in the paper side segment alternates between being inserted second and first in each respective pair 40c, 42c, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms three knuckles in the paper side segment, is inserted second, and vice versa.

As in the previous 20 shaft embodiments, the fabric has 10 non-interchanging top weft yarns (T1-10), 10 non-interchanging bottom weft yarns (B1-10) and 10 pairs of binder-top weft interchanging yarn pairs. Both the top weft yarns T1-10 and bottom weft yarns B1-10 can provide the identical weave pattern with the top and bottom warp yarns, respectively, as the previously disclosed embodiments. The binder yarn of adjacent interchanging pairs binds to a single bottom warp yarn that shifts 2 warp yarns from the previous binder yarn. For example, binder yarn I2 of the pair 40c binds to bottom warp yarn 4. Binder yarn I3 of the interchanging pair 42c shifts over two bottom warp yarns to bind to bottom warp yarn 8. Similarly, the binder yarn of the next interchanging pair binds to bottom warp yarn 12; the binder yarn of the next interchanging pair binds to bottom warp yarn 16, etc.

Referring to Fig. 5, a further embodiment of a 20 shaft, triple-layer fabric is shown. However, only one-half of the full weave repeat is illustrated. In this embodiment the fabric contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments as in the previously described embodiments. The binder yarn of all said pairs of interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp

yarns (as with the embodiment shown in Figure 3), and binds to a single bottom warp yarn, in a locked position, in regions underlying said second segments. For example, binder yarn I1 (dotted line) of interchanging pair 40d forms a first paper side segment with 6 paper side warp yarns 17, 19, 1, 3, 5 and 7, and then binds to single bottom warp yarn 14. This same relationship holds true for the binder yarns in each of the other binder pairs in the fabric, as can be seen in Fig. 5. It should be noted that each binder yarn binds to a bottom warp yarn that steps 3 to the left from the previously bound bottom warp yarn. For example, binder yarn I4 (dotted) binds to bottom warp yarn 8, which steps 3 to the left from the previously bound bottom warp yarn 14 provided by binder weft yarn I1.

The top yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but always of 4 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 7 warp pairs in the region underlying said first segments such that the stiffening effect is increased by comparison to the first embodiment which had alternative stiffening sections of 5 and 7 warp pairs respectively. For example, top weft yarn I2 of the interchanging pair 40d provides a second paper side segment with 4 paper side warp yarns 9, 11, 13 and 15 and then floats between the 7 warp pairs 17-18, 19-20, 1-2, 3-4, 5-6, 7-8 and 9-10. This same relationship exists for the top weft yarns in all of the interchanging yarn pairs, as can be seen in Fig. 5. In this embodiment the weave pattern of the non-interchanging top and bottom weft yarns is the same as in the previously disclosed embodiments. However, the relative position of the transitional warp yarns for the interchanging binder-top weft yarn pairs has been modified to change the twill pattern developed by this weave feature in the fabric paper side. As a result of this change, Fig. 5 shows only one-half of the full weave repeat. The full weave repeat includes 20 non-interchanging top weft yarn (T1-20), 20 non-interchanging bottom warp yarns (B1-20) and 20 interchanging binder-top yarn pairs (40d, 42d, 44d . . . 78d).

The fabric disclosed in Fig. 5 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms three paper side knuckles in the paper side segment alternates between being inserted first and second in each respective pair 40d, 42d, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms two knuckles in the paper side segment, is inserted second, and vice versa.

Referring to Fig. 6, an additional embodiment of a 20 shaft, triple-layer fabric is shown. This fabric contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments as in the previously disclosed embodiments. The binder yarn of all said pairs of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns (as with Figure 4), but unlike the prior embodiments the binding to a single bottom warp yarn in regions underlying said second segments herein occurs in an unlocked position. For example, the binder yarn I2 (solid line) provides a first paper side segment with the 4 paper side warp yarns 13, 15, 17 and 19, and binds, in an unlocked position, to bottom warp yarn 8. That is, although the non-interchanging bottom weft yarn B2 on one side of the interchanging pair 40e does bind to bottom warp yarn 6, immediately adjacent the bottom warp yarn 8 engaged by the binder yarn I2 of the interchanging pair 40e, the non-interchanging bottom weft yarn B1 on the other side of the interchanging pair 40e does not bind with warp yarn10 as would be required to lock the binder knuckle in position.

The top yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but always of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. For example, top weft yarn I1 (dotted line) of the interchanging binder-top weft yarn pair 40e provides a second paper side segment with the 6 paper side warp yarns 1, 3, 5, 7, 9 and 11,

and provides a stiffening section of 5 warp pairs 13-14, 15-16, 17-18, 19-20 and 1-2. As can be seen in Fig. 6, this same relationship exists for the top weft yarns of each of the other interchanging pairs in the weave repeat.

The fabric disclosed in Fig. 6 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms two paper side knuckles in the paper side segment alternates between being inserted second and first in each respective pair 40e, 42e, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms three knuckles in the paper side segment, is inserted second, and vice versa.

Referring to Fig. 7 another embodiment of a 20 shaft, triple-layer fabric in accordance with this invention is disclosed. This latter fabric contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments as in the previously described embodiments. The binder yarn of all said pairs of interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp yarns, but unlike prior embodiments wherein the binder interlaced a single bottom warp yarn, in a locked position, in regions underlying said second segments, herein the binders always interlace with two contiguous wear side warp yarns in a locked position. For example, binder yarn I1 of the interchanging binder pair 40f provides a first paper side segment of 6 paper side warp yarns 13, 15, 17, 19, 1 and 3, and then binds to adjacent bottom warp yarn 8,10 underlying a second paper side segment formed by the top weft yarn I2 (solid line). This same relationship exists for the binder yarns in all of the interchanging pairs of yarns in the weave repeat.

The top yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but always of 4 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 7 warp pairs in the region underlying said first segments such that the stiffening

effect is increased by comparison to the first embodiment. For example, the top weft yarn I2 of the interchanging pair 40f provides a second paper side segment with 4 paper side warp yarns 5, 7, 9 and 11, and also floats between the 7 warp pairs 13-14, 15-16, 17-18, 19-20, 1-2, 3-4 and 5-6. This same relationship exists for all of the top weft yarns in the other pairs of interchanging yarns.

Regarding the internal binder float lengths in Figure 7 these vary between 1 and 2 warp pairs and are thus very short to ensure a tight binding of the respective fabric layers. By way of illustration binder I1 floats between MD pair 5-6 and again between MD pair 11-12, 13-14 to give float lengths of 1 and 2 respectively. The short float lengths were achieved by the multiple wear side and paper side bindings of the binder yarn. Float length will vary according to these features.

The fabric disclosed in Fig. 7 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms three paper side knuckles in the paper side segment alternates between being inserted first and second in each respective pair 40f, 42f, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms two knuckles in the paper side segment, is inserted second, and vice versa.

Referring to Fig. 8 another embodiment of a 20 shaft, triple-layer fabric of this invention is disclosed. This latter fabric contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments as in the previously disclosed embodiments. The binder yarn of the pairs of alternate interchanging binder-top weft yarn pairs 40g, 44g, 48g, 52g and 56g provides a first paper side segment of 4 paper side warp yarns, and binds, in a locked position, to a first wear side warp yarn and also binds, in an unlocked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in regions underlying said second segments. By way of example, the binder yarn I2 (solid line) of the binder-top

weft yarn pair 40g provides a first paper side segment with the 4 paper side warp yarns 1, 3, 5 and 7, and then binds to bottom warp yarn 14, which is locked, and also to bottom warp yarn 18, which is unlocked. Specifically, the binding to bottom warp yarn 14 is locked because the non-interchanging bottom weft yarns B1 and B2 on opposite side of the binder yarn I2 binds to immediately adjacent bottom warp yarns 12 and 16, respectively. However, this locked relationship does not exist for the binding of the bottom warp yarn 18 by the binder yarn I2.

The top weft yarn of said alternate, interchanging binder-top weft yarn pairs 40g, 44g, 48g, 52g and 56g provides a second paper side segment, but of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. By way of example, the top weft yarn I1 (dotted line) of the interchanging pair 40g provides a second paper side segment with the 6 paper side warp yarns 9, 11, 13, 15, 17 and 19, and also floats between the 5 warp pairs 1-2, 3-4, 5-6, 7-8 and 9-10.

The above alternating pairs of interchanging yarns, which have the above described weave relationship, alternate with interchanging pairs 42g, 46g, 50g, 54g and 58g. In these latter pairs of interchanging binder-top weft yarns the binder yarn provides the longer paper side segment of 6 paper side warp yarns and binds, in a locked position, to a first wear side warp yarn and also binds, in an unlocked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in the region underlying the shorter segment of 4 paper side warp yarns provided by the top yarn. By way of example, the binder yarn I4 (dotted line) of the interchanging pair 42g provides a paper side segment with the 6 paper side warp yarns 13, 15, 17, 19, 1 and 3, and binds in a locked position to bottom warp yarn 8 and in an unlocked position to bottom warp yarn 12.

In addition, in the second set of alternate binder-top pairs 42g, 46g, 50g, 54g and 58g the stiffening section length is increased to 7 pairs of warp yarns. By way of explanation, the stiffening section in the pair 42g is provided by the top weft yarn I3 (solid line) floating between warp pairs 13-14, 15-16, 17-18, 19-20, 1-2, 3-4 and 5-6.

In all of the interchanging binder-top weft pairs in this embodiment (Fig. 8) the first and second warp yarns of the wear side fabric which are interlaced with the binder yarn are situated on either side of an intervening wear side fabric warp yarn. For example, in the interchanging pair 40g, the first and second warp yarns 14 and 18 of the wear side fabric that are interlaced with the binder yarn I2 include intervening wear side fabric warp yarn 16 therebetween.

The fabric disclosed in Fig. 8 employs a reversing insertion order for paper side segment lengths made by respective members of the interchanging yarn pairs but the binder and top weft member insertion order is the same for each pair. This technique was also used in Figure 2 and so will not be described in further detail herein.

Table 2 shows the influence of the interchanging yarn pair material. In particular the shrinkage of the material has a strong influence on the resulting properties. In both samples made according to Figure 8 polyamide yarns were used for both yarns in the interchanging yarn pair. In the LS version a relatively low shrinkage material was used whereas in the HS version a relatively high shrink yarn was used. Herein low shrink yarn is defined as shrinking by no more than 6.0% at 180°C when tested according to the manufacturer's instructions. Examples of such yarns include Teijin Monofilament products 804A and 807A. High shrink materials are herein defined as shrinking by more than 6.0% at 180°C. Examples of such yarns include Teijin Monofilament products 814A and 824A and Shakespeare Monofilament NX315. The fabric sample made using the low shrink binder material was found to be significantly thicker, although still

very useable for many applications, but also gave stiffness benefits on account of this feature.

Consequently it is demonstrated that when using interchanging yarns of the same polymer type it is possible to derive benefits due to selected yarn thermal shrinkage properties. The interchanging yarns of a pair can both be made with both using either high or low shrink yarns of the same polymer or the low and high shrink yarns can be mixed within a given interchanging yarn pair.

Note also the relative fineness of the fabric samples with approximately 66 MD yarns/cm and MD diameter of 0.14/0.18mm. It is expected that other desirable combinations of MD diameters (0.13/0.17) and CD diameters on paper side of 0.10 to 0.15mm and binder diameters of 0.10 to 0.15mm and MD yarns/cm (60-70/cm) would give similar results

Table 2

	Fig 8 - LS	Fig 8- HS
MD Dia PS/WS(mm)	0.14/0.18	0.14/0.18
CD Dia PS/WS(mm)	0.13/0.27	0.13/0.27

Interchanging pair Dia (mm)	0.13	0.13
MD/CD Yarns/cm	65.8/58.5	65.8/57.8
Thickness (mm)	0.873	0.841
Void volume (cm^3/m^2)	546	506
CD Bend Stiff Ratio	107	100
PS Support Points ($/cm^2$)	1283	1267

Referring to Fig. 9, a partial weave pattern is shown of another 20 shaft, triple-layer fabric in accordance with this invention. The complete weave pattern includes 10 non-interchanging top weft yarns, 10 non-interchanging bottom weft yarns and 10 pairs of binder-top weft interchanging yarn pairs as in a number of the previously disclosed embodiments. In this embodiment the weave patterns of the 10 non-interchanging top weft yarns and the 10 interchanging bottom weft yarns are identical to that illustrated, at least partially, in all previous embodiments of the invention although, as will be seen in later embodiments this is not a limiting feature of the present invention.

In Fig. 9, only two of the 10 pairs of interchanging yarns are illustrated at 40h and 42h. As in the previous embodiments, all of the interchanging yarn pairs

are binder-top weft yarns which interchange to provide two paper side segments. The binder yarn of each pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns, and binds, in an unlocked position, to a first wear side warp yarn and also binds, but in a locked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in regions underlying said second segments. By way of further explanation, binder yarn I2 (solid line) provides a paper side segment with 4 warp yarns 17, 19, 1 and 3, and binds to bottom warp yarn 10 in an unlocked position and to bottom warp yarn 14 in a locked position.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. By way of further explanation, the top weft yarn I1 (dotted line) provides a second paper side segment with 6 paper side warp yarns 5, 7, 9, 11, 13 and 15, and floats between 5 warp pairs 17-18, 19-20, 1-2, 3-4 and 5-6 between binding to top warp yarns 15 and 7.

In all of the interchanging binder-top weft pairs in this embodiment the first and second warp yarns of the wear side fabric which are interlaced with the binder yarn are situated on either side of an intervening wear side fabric warp yarn, in the same manner as previously described in connection with the fabric shown in Fig. 8.

The fabric disclosed in Fig. 9 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms two paper side knuckles in the paper side segment alternates between being inserted second and first in each respective pair 40h, 42h, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which

forms three knuckles in the paper side segment, is inserted second, and visa versa.

Referring to Fig. 10, a partial weave pattern is shown of another 20 shaft, triple-layer fabric in accordance with this invention. The complete weave pattern includes 10 non-interchanging top weft yarns, 10 non-interchanging bottom weft yarns and 10 pairs of binder-top weft interchanging yarn pairs as in a number of the previously disclosed embodiments. In this embodiment the weave patterns of the 10 non-interchanging top weft yarn and the 10 interchanging bottom weft yarns are identical to that illustrated, at least partially, in all previous embodiments of the invention, although, as will be seen in later embodiments, this is not a limiting feature.

In Fig. 10, only two of the 10 pairs of interchanging yarns are illustrated at 40i and 42i. As in the previous embodiments, all of the interchanging yarn pairs are binder-top weft yarns which interchange to provide two paper side segments. The binder yarn of each pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns, and binds, in a locked position, to a first wear side warp yarn and also binds, but in an unlocked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in regions underlying said second segments. By way of further explanation, binder yarn I2 (solid line) provides a paper side segment with 4 warp yarns 13, 15, 17 and 19 and binds to bottom warp yarn 4 in a locked position and to bottom warp yarn 10 in an unlocked position.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. By way of further explanation, the top weft yarn I1 (dotted line) provides a second paper side

segment with 6 paper side warp yarns 1, 3, 5, 7, 9 and 11, and floats between 5 warp pairs 13-14, 15-16, 17-18, 19-20 and 1-2 between binding to top warp yarns 11 and 3.

This embodiment (Fig. 10) differs from the embodiment of Fig. 9, in that the first and second warp yarns of the wear side fabric which are interlaced with the binder yarn of each interchanging pair are situated on opposed sides of two intervening wear side fabric warp yarns to thereby provide an additional stiffening yarn section.

The fabric disclosed in Fig. 10 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms two paper side knuckles in the paper side segment alternates between being inserted second and first in each respective pair 40i, 42i, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms three knuckles in the paper side segment, is inserted second, and visa versa.

Table 3 contrasts sample fabric of the invention (according to Figure 10) with sample fabric according to the Ward '197 patent. It shows reductions in void volume and caliper while showing a significant enhancement in CD bend stiffness of the invention, i.e., a 14% increase. Both sample fabrics utilised 0.14/0.18mm paper side and wear side MD yarn diameter respectively at approximately 66 MD/cm. Although selected wear side CD diameter was 0.27mm other yarn diameters such as 0.20mm to 0.30mm are very suitable for use in this invention. This CD diameter range is also suitable for fabric made on same warp set but with 1:1 or 3:2 CD ratio.

Table 3

	Ward '197	Fig 10
MD Dia PS/WS(mm)	0.14/0.18	0.14/0.18
CD Dia PS/WS(mm)	0.13/0.27	0.13/0.27
Interchanging pair Dia (mm)	0.13	0.13
MD/CD Yarns/cm	65.9/58.5	65.8/58.5
Thickness (mm)	0.831	0.816
Void volume (cm^3/m^2)	502	486
CD Bend Stiff Ratio	100	114
PS Support Points ($/cm^2$)	1285	1283

Referring to Fig. 11, yet another embodiment of a 20 shaft, triple-layer fabric in accordance with this invention is disclosed. This latter fabric contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments as in all of the other previously disclosed embodiments. The binder yarn of each pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 2 paper side warp yarns, and binds, in a locked position, to a first wear side warp yarn and also binds, again in a locked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in regions underlying said second segments. By way of further explanation, the binder yarn I2 (solid line) of the interchanging pair 40j provides a first paper side segment with 2 paper side warp yarns 17 and 19, and binds, in a locked position to bottom warp yarns 4 and 14, which are also spaced-apart by 4 intervening bottom warp yarns 6, 8, 10 and 12.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but of 8 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 3 warp pairs in the region underlying said first segments. By way of further explanation, top weft yarn I1 (dotted line) provides a paper side segment with 8 paper side warp yarns 1, 3, 4, 7, 9, 11, 13 and 15, and then floats between 3 warp pairs 17-18, 19-20 and 1-2.

As noted above, in all the interchanging binder-top weft pairs in this embodiment of the invention the first and second bottom warp yarns of the wear side fabric which are interlaced with the binder yarn are situated on either side of four intervening wear side fabric warp yarns to thereby provide an additional stiffening yarn section.

The fabric disclosed in Fig. 11 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms one paper side knuckle in the paper side segment alternates between being inserted

second and first in each respective pair 40j, 42j, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms four knuckles in the paper side segment, is inserted second, and vice versa.

Table 4 contrasts sample fabric of the invention (according to Figure 11) with sample fabric according to the Ward '197 patent. It shows desirable reductions in void volume and caliper while showing a significant enhancement in CD bend stiffness of the invention, i.e., a 22% increase. Both sample fabrics utilised 0.14/0.18mm paper side and wear side MD yarn diameter respectively at approximately 66 MD/cm.

Table 4

	Ward '197	Fig 11
MD Dia PS/WS(mm)	0.14/0.18	0.14/0.18
CD Dia PS/WS(mm)	0.13/0.27	0.13/0.27
Interchanging pair Dia (mm)	0.13	0.13

MD/CD Yarns/cm	65.9/58.5	65.8/58.5
Thickness (mm)	0.831	0.826
Void volume (cm^3/m^2)	502	493
CD Bend Stiff Ratio	100	122
PS Support Points ($/cm^2$)	1285	1283

Referring to Fig. 12, a partial weave pattern is shown of another 20 shaft, triple-layer fabric in accordance with this invention. The complete weave pattern includes 10 non-interchanging top weft yarns, 10 non-interchanging bottom weft yarns and 10 pairs of binder-top weft interchanging yarn pairs as in a number of the previously disclosed embodiments. In this embodiment the weave pattern of the 10 non-interchanging top weft yarns is identical to that illustrated in the earlier disclosed embodiments, i.e., a plain weave pattern. However, the weave pattern of the non-interchanging bottom weft yarns, e.g., B1, B2, B3, etc. is different from the previously disclosed embodiments, as will be discussed later herein.

In Fig. 12, only two of the 10 pairs of interchanging yarns are illustrated at 40k and 42k. As in the previous embodiments, all of the interchanging yarn pairs are binder-top weft yarns which interchange to provide two paper side segments. The binder yarn of each pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns, and binds, in an unlocked

position, to a single wear side warp yarn located in regions underlying said second segments. By way of further explanation, binder yarn I2 (dotted line) provides a paper side segment with 4 warp yarns 11, 13, 15 and 17 and binds to bottom warp yarn 6 in an unlocked position.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. By way of further explanation, the top weft yarn I1 (solid line) provides a second paper side segment with 6 paper side warp yarns 19, 1, 3, 5, 7, and 9, and floats between 5 warp pairs 11-12, 13-14, 15-16, 17-18 and 19-20 between binding to top warp yarns 9 and 1.

This embodiment (Fig. 12) differs from the previous embodiment in that the non-interchanging wear side weft yarn interlaces with the wear side warp yarns to provide a weave pattern with longer float lengths to thereby enhance fabric CD stiffness. By way of example, wear side weft yarn B3 floats under 7 adjacent bottom warp yarns (i.e., 6, 8, 10, 12, 14, 16 and 18) between binding to bottom warp yarns 4 and 20. This same relationship exists for the remaining, non-interchanging wear side yarns. In addition to providing longer wear side CD yarn float length, for lifetime and stiffness benefits, there is now provided a wear side weave pattern wherein two wear side MD yarns interlace with a single wear side CD yarn within one repeat of the weave pattern.

The fabric disclosed in Fig. 12 employs a reversing insertion order for the interchanging yarn pairs. That is, the binder yarn of each pair, which forms two paper side knuckles in the paper side segment alternates between being inserted second and first in each respective pair 40k, 42k, etc. Likewise, when the binder yarn is inserted first, the top weft yarn of the corresponding pair, which forms three knuckles in the paper side segment, is inserted second, and vice versa.

Referring to Fig. 13, a further embodiment of a 20 shaft, triple-layer fabric in accordance with this invention is partially shown. This fabric, like all of the previously disclosed fabrics, contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments. This embodiment, unlike the previously described embodiments has an effective paper side to wear side CD ratio of one to one, rather than two to one. The full weave repeat, which is not illustrated, includes 10 (ten) paper side wefts, 20 wear side wefts and 10 pairs of interchanging binder-top weft yarns. The illustrated embodiment shows 3 top weft yarns T1, T2 and T3, 5 bottom weft yarns B1 through B5 and two pairs of binder-top weft interchanging yarns 40L, 42L.

The binder yarn of a first pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns, and binds in a locked position, to a single bottom warp yarn in regions underlying said second segments. By way of further explanation, binder yarn I2 (solid line) of the interchanging pair 40L provides a first paper side segment of 4 paper side warp yarns 13, 15, 17 and 19, and binds in a locked position to bottom warp yarn 8.

The top yarn of said first interchanging binder-top weft yarn pairs provides a second paper side segment, but of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. By way of further explanation, top weft yarn I1 (dotted line) of interchanging binder pair 40L provides a paper side segment of 6 paper side warp yarns 1, 3, 5, 7, 9 and 11, and then floats between the 5 warp pairs 13-14, 15-16, 17-18, 19-20 and 1-2, between binding to top warp yarns 11 and 3.

The above-described weave arrangement is provided in alternate pairs of binder-top weft interchanging yarns. These latter interchanging yarn pairs alternate with yarn pairs having a different arrangement, as is exemplified by yarn pair 42L.

The binder yarn in the interchanging yarn pair 42L, and in the other yarn pairs that alternate with the first group of yarn pairs, provides the longer paper side segment of 6 paper side warp yarns and binds in a locked position, to a single wear side warp yarn in the region underlying the shorter segment of 4 paper side warp yarns provided by the top weft yarn. In said second alternate binder-top pairs the stiffening section length provided by the top weft interchanging yarn is increased to 7 pairs of warp yarns. By way of example, the binder yarn I4 of the interchanging pair 42L provides the paper side segment with 6 paper side warp yarns 9, 11, 13, 15, 17 and 19, and binds to single bottom warp yarn 6 underlying the other paper side segment. The top weft yarn I3 has a stiffening section length of the 7 pairs of warp yarns 9-10, 11-12, 13-14, 15-16, 17-18, 19-20 and 1-2. As noted above, this embodiment provides a paper side to wear side effective CD ratio of 1:1 unlike the prior embodiments which all provided an effective CD ratio of 2 paper side paths: 1 wear side yarn.

By comparison to the prior embodiments, which had a 2:1 CD ratio, the fabric of Figure 13 has a different distribution of its CD yarns to the paper side and wear side fabrics. If we consider two otherwise identical fabrics except for 2:1 and 1:1 CD ratio the 1:1 CD ratio fabric will provide more CD yarns on the wear side for abrasion resistance whereas the 2:1 CD ratio fabric will provide more paper side yarns for higher sheet quality.

As with all embodiments, Figure 13 variants can be made wherein the interchanging yarn pairs possess yarn stiffening sections that are either all long, all short, or alternating or with some other percentage or arrangement disposed as long or short sections. Similarly reversing of long-short paper side segments and/or top-binder yarns may be made.

Referring to Fig. 14, yet another embodiment of a 20 shaft, triple-layer fabric is partially shown. Specifically, the weave paths of 4 paper side wefts T1 through T4, 4 wear side wefts B1 through B4, and 2 pairs of interchanging

binder-top weft yarns 40m, 42m are shown. The full weave repeat includes 40 paper side wefts, 40 wear side wefts and 20 pairs of interchanging binder-top weft yarns, thereby providing a paper side-to-wear side CD ratio of three-to-two.

The embodiment shown in Fig. 14, like all of the previous embodiments, includes pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments. The binder yarn of a first set of alternating, interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp yarns, and binds in a locked position, to a single bottom warp yarn in regions underlying said second segments. By way of example, the binder yarn i2 (dotted line) of interchanging pair 40m provides a first paper side segment of 6 paper side warp yarns 13, 15, 17, 19, 1 and 3.

The top weft yarn of said first set of alternating, interchanging binder-top weft yarn pairs provides a second paper side segment, but of 4 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 7 warp pairs in the region underlying said first segments. By way of example, top weft yarn i1 (solid line) of the interchanging pair 40m provides a second paper side segment with 4 paper side warp yarns 5, 7, 9 and 11, and the floats between 7 warp pairs 13-14, 15-16, 17-18, 19-20, 1-2, 3-4 and 5-6 between binding to top warp yarns 11 and 7.

The set of binder-top weft yarn pairs having the arrangement of 40m alternate with a second set of binder-top weft yarn pairs.

In the second set of binder-top weft yarn pairs the binder yarn provides the shorter paper side segment of 4 paper side warp yarns and binds in a locked position, to a single wear side warp yarn in the region underlying the longer segment of 6 paper side warp yarns provided by the top weft yarn. In said second set of alternating binder-top pairs the stiffening section length provided by the top weft yarn is decreased to 5 pairs of warp yarns. By way of example,

binder-top weft yarn pair 42m is representative of the second set of alternating pairs. The binder yarn i4 (solid line) in this pair provides the paper side segment of 4 paper side warp yarns 11, 13, 15 and 17. The top weft yarn i3 (dotted line) of this pair provides a paper side segment of 6 paper side warp yarns 19, 1, 3, 5, 7 and 9, and floats between 5 pairs of warp yarns 11-12, 13-14, 15-16, 17-18 and 19-20.

This embodiment of the invention provides a paper side to wear side effective CD ratio of 3:2 unlike the prior embodiments which provided an effective CD ratio of either 2:1 or 1:1. For an identical number of woven yarns, a 3:2 effective CD ratio will provide a significant increase in wear side yarns and the same number of paper side yarns as a 2:1 CD ratio fabric such that life potential is increased. This is because the 3:2 ratio fabric has less pairs of interchanging yarns which only give a single effective yarn path.

The top weft yarns all provide a plain weave pattern. The bottom weft yarns are a 5 shed repeat (as were all prior embodiments with the exception of Figure 12), with each bottom weft stepping over two bottom warps relative to the previous bottom weft. To further explain, bottom weft B1 binds to bottom warps 8 and 18. Bottom weft B2 steps over two bottom warps relative to B1 to bind to bottom warps 4 and 14. Bottom weft B3 steps over two bottom warps relative to B2 to bind to bottom warps 20 and 10. And bottom weft B4 steps over two bottom warps relative to B3 to bind to bottom warps 16 and 6. This same relationship exists for the remaining bottom weft yarns in the repeat. It should be noted that the 3:2 CD ratio is not limited to fabric with 5 shaft wear side, or indeed plain weave paper side, but may be deployed with 10,16, 24,28, 32 shaft fabrics as non-limiting examples.

Regarding the internal binder floats in Figure 14 it can be seen that these vary with binder i2 passing between 3 and 1 warp pairs i.e. 5-6, 7-8, 9-10 and then 13-14, respectively, whereas binder i4 passes between 4 and 2 warp pairs,

i.e., 5-6, 7-8, 9-10, 1-12 and then 19-20, 1-2 respectively. This is not a limiting aspect of the fabrics with 3:2 CD ratio as internal float can be the same for all interchanging pairs. Similarly it is not an essential requirement that the 3:2 CD ratio fabrics have locked single wear side binding knuckles as the binders may interlace with multiple adjacent or contiguous wear side MD yarns in locked or unlocked positions.

Referring to Fig. 15, a further embodiment of a fabric of this invention is a 28 shaft, triple-layer fabric. The full weave repeat is shown, including 14 paper side wefts T1-T14, 14 wear side wefts B1-B14 and 14 pairs of interchanging binder-top weft yarn 40n, 42n . . . 66n. As in all of the previous embodiments the pairs of interchanging binder-top weft yarns interchange to provide two paper side segments.

The binder yarn of each pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp yarns, and binds, in an unlocked position, to a first wear side warp yarn and also binds, again in an unlocked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in regions underlying said second segments. By way of example the binder yarn I2 (solid line) provides a first paper side segment of 6 paper side warp yarns 5, 7, 9, 11, 13 and 15, and then binds, in unlocked positions to bottom warp yarns 24 and 28.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, but of 8 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 7 warp pairs in the region underlying said first segments. By way of example, top weft yarn I1 (dotted line) of the pair 40n provides the second paper side segment of 8 paper side warp yarns 17, 19, 21, 23, 25, 27, 1 and 3, and then floats between the 7 warp pairs 5-6, 7-8, 9-10, 11-12, 13-14, 15-16 and 17-18.

In all the interchanging binder-top weft pairs in this embodiment the first and second warp yarns of the wear side fabric which are interlaced with the binder yarn are situated on either side of an intervening wear side fabric warp yarn.

Variants on Figure 15 can be made regarding the binder wear side interlacings. It is quite feasible to modify these bindings to interlace in a contiguous or adjacent manner, for example, up to 4 contiguous wear side warps to thereby enhance delamination resistance and to reduce binder internal float length

Regarding the paper side transition points these still number two for each interchanging pair. However, it is now two for every 28 MD yarns and not for every 20 MD yarns as with prior embodiments, i.e., there is the possibility of reduced wiremark due to reduction in the transition points per unit area. This concept has been described in some detail in co-pending application serial No. 60/473,664, titled "High Shaft Fabrics" which was filed on May 23, 2003. The subject matter of this '664 application is herein fully incorporated by reference.

Referring to Fig. 16, a partial weave repeat of another embodiment of a fabric of this invention is shown. This fabric is a 32 shaft, triple-layer fabric, which, like all of the previous embodiments, contain pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments. Fig. 16 shows the weave paths of 3 paper side wefts T1-T3, 3 wear side wefts B1-B3 and 2 pairs of interchanging binder-top weft yarns 40p, 42p. The full weave repeat includes 16 paper side wefts, 16 wear side wefts and 16 pairs of interchanging binder-top weft yarns.

The paper side wefts all form a plain weave pattern within each repeat. The wear side wefts employ an 8 shaft repeat and step three to the right relative to the immediately preceding wear side weft. To further explain, wear side weft

B1 binds to bottom warps 2 and 18. The next succeeding wear side weft B2 steps three to the right relative to B1 and binds with bottom warps 8 and 24. The next succeeding wear side weft B3 steps three to the right relative to B2 and binds with bottom warps 14 and 30. This arrangement continues for the rest of the bottom weft yarns within the repeat.

The binder yarn of each pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 8 paper side warp yarns, and binds, in an unlocked position, to a first wear side warp yarn and also binds, again in an unlocked position, to a second wear side warp yarn to provide additional delamination resistance, both bindings being located in regions underlying said second segments. By way of example, binder yarn I1 (solid line) of the interchanging pair 40p provides a first paper side segment of 8 paper side warp yarns 25, 27, 29, 31, 1, 3, 5 and 7, and then binds, in unlocked positions to bottom warp yarns 14 and 22.

The top weft yarn of said interchanging binder-top weft yarn pairs provides a second paper side segment, also of 8 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 9 warp pairs in the region underlying said first segments. By way of example, top weft yarn I2 (dotted line) of the interchanging pair 40p provides a second paper side segment with 8 paper side warp yarns 9, 11, 13 ,15,17, 19, 21 and 23, and then floats between the 9 warp pairs 25-26, 27-28, 29-30, 31-32, 1-2, 3-4, 5-6, 7-8 and 9-10 between binds to top warp yarns 23 and 11.

In all the interchanging binder-top weft pairs in this embodiment the first and second warp yarns of the wear side fabric which are interlaced with the binder yarn are situated on either side of 3 intervening wear side fabric warp yarns to thereby provide an additional stiffening yarn section. By way of example, the first and second bottom warp yarns 14 and 22, which are interlaced with the binder yarn I1 are situated on opposite sides of the 3 intervening wear

side fabric warp yarns 16, 18 and 20. In this embodiment there is no reversal of the insertion order because each of the two paper side segments are of the same length, i.e., 9 paper side warp yarns in length. However, it is not a limiting feature of the invention that, where possible the segments must be of equal length, as, regarding the embodiment shown in Figure 16 at least one interchanging yarn pair could be modified advantageously to provide paper side segments of different length. For example, decreasing the paper side segment length of top weft i2 would increase the stiffening section of the same yarn. In this instance matching binder yarn i1 must make additional interlacing on the paper side thus further enhancing delamination resistance.

Still regarding segments of different length but in multi-segment binder-top embodiments it is feasible to provide at least one pair of interchanging binder-top yarns wherein each member of the pair provides two segments each of different lengths. This technique has been disclosed in co-pending application Serial No. 60/477,376, titled Fabrics with Multi-Segment, Paired, Interchanging Yarns, filed on June 10, 2003. The subject matter of this latter '376 is hereby fully incorporated by reference herein. In the two segment embodiments it is possible to vary segment lengths from one pair of interchanging binder-top yarns to another of said pairs. Benefits sought by this technique can include optimisation of delamination resistance or stiffening segment or break up of transitional warp yarn twill lines.

In both multi-segment and 2 segment binder-top embodiments it is also possible to redistribute transitional warp yarn twill lines by placing a different number of paper side CD yarns between at least three adjacent pairs of interchanging binder-top yarns.

Returning to discuss Figure 16 directly, although paper side segment lengths are equal, reversing of the binder and top yarn insertion order may still be

made to prevent a regular spacing and twill line developing from the knuckles of the binder yarns where they interlace the wear side warp yarns.

Referring to Fig. 17, a partial weave repeat of another 20 shaft, triple-layer fabric of this invention is shown. Fig 17 shows 5 paper side wefts T1-T5, 5 wear side wefts B1-B5, 2 pairs of interchanging binder-top weft yarns 42q, 46q and 2 pairs of interchanging binder-binder weft yarns 40q, 44q. The full weave repeat comprises 20 paper side wefts, 20 wear side wefts, 10 pairs of interchanging binder-top weft yarns and 10 pairs of interchanging binder-binder weft yarns that alternate with the interchanging binder-top weft yarns.

Still referring to Fig. 17, the fabric includes pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments as in all of the previous embodiments of this invention. The binder yarn of a first pair of interchanging binder-top weft yarn pairs provides a first paper side segment of 4 paper side warp yarns, and binds in a locked position, to a single bottom warp yarn in regions underlying said second segments. By way of example, binder yarn I3 (solid line) provides a first paper side segment of 4 paper side warp yarns 13, 15, 17 and 19, and binds in a locked position to bottom warp yarn 8.

The top weft yarn of said first interchanging binder-top weft yarn pair provides a second paper side segment, but of 6 paper side warp yarns, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs in the region underlying said first segments. By way of example top weft yarn I4 (dotted line) provides a second paper side segment with 6 paper side warp yarns 1, 3, 5, 7, 9 and 11, and floats between the 5 warp pairs 13-14, 15-16, 17-18, 19-20 and 1-2.

The next binder-top weft yarn pair 46q, which is spaced from the preceding binder-top weft yarn pair 42q by an interchanging binder-binder pair 44q, has a different arrangement from the pair 42q. Specifically the binder-top

weft yarn pair 46q includes a binder yarn I8 that provides a first paper side segment with 6 paper side warp yarns 9, 11, 13, 15, 17 and 19 and binds to a single bottom warp yarn 6, which is locked. The top weft yarn I7 of the pair 46q provides a paper side segment of 4 paper side warp yarns 1, 3, 5 and 7, and then floats between 7 pairs of warp yarns 9-10, 11-12, 13-14, 15-16, 17-18, 19-20 and 1-2.

The interchanging binder-top weft yarn pairs alternate with second pairs of interchanging weft yarns which are disposed as binder-binder interchanging weft pairs. In a first pair 40q of said binder-binder pairs a first binder yarn I1 (dotted line) provides the longer paper side segment of 6 paper side warp yarns 17, 19, 1, 3, 5 and 7 and binds in a locked position, to a single wear side warp yarn 14 in the region underlying the shorter segment of 4 paper side warp yarns 9, 11, 13 and 15 provided by the second binder member I2 (solid line) of the interchanging pair. This same arrangement exists for binder yarn I5 (dotted line) and I6 (solid line), there being no reversal of the yarns. The inclusion of interchanging binder pairs alternating with the two different types of binder-top weft yarns increases fabric delamination resistance. It is within the scope of the invention to vary the number and arrangement of interchanging binder-binder yarn pairs, as well as the two different types of binder- top weft yarn pairs.

Referring to Fig. 18, one pair of interchanging binder-top weft yarns forming part of a 20 shaft, triple-layer fabric of this invention is shown. This binder-top weft yarn pair, like all of such binder-top weft yarn pairs in this fabric and all of the previously described fabrics, contains a pair of yarns that interchange to provide two paper side segments. The binder yarn I1 of at least one pair 40r of interchanging binder-top weft yarn pairs provides a first paper side segment of 5 paper side warp yarns 19, 1, 3, 5 and 7, and binds to a single wear side warp yarn 16 located in regions underlying said second segments. The top weft yarn I2 of said interchanging binder-top weft yarn pair 40r provides a second paper side segment, also of 5 paper side warp yarns 9, 11, 13, 15 and

17, and floats between paper side and wear side fabrics to provide a stiffening section of 6 warp pairs 19-20, 1-2, 3-4, 5-6, 7-8 and 9-10 in the region underlying said first segments. The interchanging yarn pair in this embodiment provides long CD orientated floats on the paper side fabric outer surface, as shown in Fig 18. A paper side fabric surface dominated by CD floats may be desirable, for example, in Tissue and some Board or Brown paper grades where such a fabric surface may allow a desirably rapid initial dewatering. The wear side weave can be selected from the group including 5 or 10 shaft sateen with either one or multiple contiguous or adjacent MD-CD yarn interlacing per wear side fabric weft yarn i.e. acceptable wear side fabric weft paths include: over 1-under 4 (warps); over 1-under 1-over 1-under 7; over 2-under 8 etc. Furthermore, the paper side to wear side CD ratio may be selected from the group including 1:1, 2:1, 3:2, 4:3, 5:4 etc., although a single wear side bind arrangement was shown it is possible to provide the binder with multiple adjacent or contiguous wear side bindings.

Referring to Fig. 19, one pair of interchanging binder-top weft yarns employed in a 24 shaft, triple-layer fabric of this invention is shown. This fabric like all of the preceding embodiments contains pairs of interchanging binder-top weft yarns which interchange to provide two paper side segments. The binder yarn I1 of at least one pair 40s of interchanging binder-top weft yarn pairs provides a first paper side segment of 6 paper side warp yarns 1. 3. 5. 7. 9 and 23, and binds to a single wear side warp yarn 18 located in regions underlying said second segments. The top weft yarn of said interchanging binder-top weft yarn pair 40s provides a second paper side segment, also of 6 paper side warp yarns 11, 13, 15, 17, 19, and 21, and floats between paper side and wear side fabrics to provide a stiffening section of 7 warp pairs 23-24, 1-2, 3-4, 5-6, 7-8, 9-10 and 11-12 between binding to spaced-apart top warp yarns 21 and 13 in the paper side region of the second segment. The interchanging yarns in the binder-top weft yarn pairs in this embodiment each provide two CD orientated floats over two warp yarns on the paper side fabric outer surface. A paper side fabric surface dominated by CD floats may be desirable, for example, in Tissue and

some Board or Brown paper grades where such a fabric surface may allow a desirably rapid initial dewatering. The wear side weave can be selected from the group including 3, 6 or 12 shaft regular/irregular twills or sateens, as are known in the art, with either one or multiple contiguous or adjacent MD-CD yarn interlacing per wear side fabric weft yarn i.e. acceptable wear side fabric weft paths include: over 1-under 5 (warps); over 1-under 1-over 1-under 9 etc. Although the members of the interchanging pair illustrated possess an equal number of paper side floats and equal sized floats this is not a requirement of this invention. For example either the binder or the top weft members of at least one pair of interchanging weft yarns may provide one or three of the four CD orientated paper side floats. Such variants allow fabric CD bending stiffness or fabric delamination values to be enhanced by increasing top weft/binder stiffening float or by increasing wear side bindings in the disclosed manner of contiguous or adjacent.

Referring to Fig. 20, an interchanging binder-top weft yarn pair used in a 20 shaft, triple layer fabric of this invention is illustrated. This binder-top weft yarn 40t , like all of such interchanging yarn pairs in the previously described embodiments, interchange to provide two paper side segments. Unlike all previous embodiments it will be noted that the transitional point of the interchanging yarns occurs between two contiguous paper side warp yarns and is not located underneath any single paper side warp yarn. By way of example, the interchanging point between binder yarn I1 and top weft yarn I2 is between contiguous paper side warp yarns 9 and 11 and also between 19 and 1. The binder yarn I1of at least one pair of interchanging binder-top weft yarn pairs, as shown in Fig. 20, provides a first paper side segment of 5 paper side warp yarns 1, 3, 5, 7 and 9, and binds to a single wear side warp yarn 16 located in regions underlying said second segment. The top weft yarn I2 of said interchanging binder-top weft yarn pair 40t provides a second paper side segment, also of 5 paper side warp yarns 11, 13, 15, 17 and 19, and floats between paper side and wear side fabrics to provide a stiffening section of 5 warp pairs 1-2, 3-4, 5-6, 7-8

and 9-10 in the region underlying said first segment. The interchanging yarn pairs 40t employed in this embodiment each provide two CD orientated floats, each over two warp yarns on the paper side fabric outer surface. A paper side fabric surface dominated by CD floats may be desirable, for example, in Tissue and some Board or Brown paper grades where such a fabric surface may allow a desirably rapid initial dewatering. The wear side weave can be selected from the group including 5 or 10 shaft sateen with either one or multiple contiguous or adjacent MD-CD yarn interlacing per wear side fabric weft yarn i.e. acceptable wear side fabric weft paths include: over 1-under 4 (warps); over 1-under 1-over 1-under 7; over 2-under 8 etc. Although the members of the interchanging pair illustrated possess equal number of paper side floats and equal sized floats this is not a requirement of this invention. For example either the binder or the top weft members of at least one pair of interchanging weft yarns may provide one or three of the four CD orientated paper side floats. Such variants allow fabric CD bending stiffness or fabric delamination values to be enhanced by increasing top weft/binder stiffening float or by increasing wear side bindings.

It should be understood that the binder-top weft yarn pairs 40r, 40s and 40t disclosed for use in fabrics of this invention can be employed as all of the interchanging yarns in the respective fabrics, or only some of the interchanging yarns in such fabrics. In accordance with the broadest aspects of the invention, the identified binder-top weft yarn pair can be employed only once in each repeat of the respective fabric. However, most preferably the identified binder-top weft yarn pair makes up all of the interchanging yarn pairs in the respective fabrics.

It also should be noted, that one or more binder-binder yarn pairs may be employed in the various embodiments of this invention, in addition to the embodiment of Fig. 17, which specifically includes binder-binder interchanging yarn pairs in the disclosed structure.

Referring to Fig. 21, a summary chart discloses various features of the embodiments of this invention specifically disclosed in Figs. 2 through 20. This chart includes 10 columns. An explanation of this chart will be given with respect to the embodiment shown in Fig. 2. From that explanation a person skilled in the art clearly will understand the data with respect to the remaining embodiments of Figs. 3-20.

The first row of the summary chart, following the header row, includes structural features of the embodiment disclosed in Fig. 2.

The second column specifies that the fabric of Fig. 2 is a 20 shaft repeat.

The third column specifies that the effective ratio of cross-direction (CD) paper side (PS) yarns to wear side (WS) yarns is 2:1.

The fourth column specifies that the interchanging top weft yarns of the interchanging top weft-binder yarn pairs alternate between providing two paper side (PS) knuckles and three paper side knuckles.

The fifth column specifies that the interchanging binder yarns of the pairs of interchanging top weft-binder yarn pairs alternate between providing three paper side (PS) knuckles and two paper side knuckles. Thus when the interchanging top weft yarn provides two paper side knuckles the binder yarn of the pair provides three paper side knuckles, and vice versa.

The sixth column specifies that the segment lengths of the interchanging yarn pairs are reversing in the disclosed embodiment.

The seventh column specifies that the binder yarn of each of the interchanging top weft-binder yarn pairs is always inserted first.

The eighth column specifies that the length of the stiffening sections provided by interchanging top weft yarns alternate between 7 warp pairs (when the top weft yarn forms 2 paper side knuckles) and 5 warp pairs (when the top weft yarn forms 3 paper side knuckles).

The ninth column specifies that the binder yarns of the interchanging yarn pairs do not provide any stiffening sections.

The tenth column specifies that the binder yarns of the interchanging yarn pairs do not interlace with multiple wear side warp yarns within each repeat. That is the binder yarns interlace with only a single wear side warp yarn within each 20 shaft repeat.

Based on the above explanation, the various features of the other embodiments of this invention would be readily understood by a person skilled in the art. Therefore, no further explanation is provided herein.

It also should be noted that the yarn diameters of the paper side warp yarns and the wear side warp yarns can be varied, and preferably are different from each other. The most preferred relationships of the diameters of the paper side warp yarns and the wear side warp yarns is disclosed in the Summary of the Invention and will not be repeated herein for purposes of brevity. Suffice it to state that the specified yarn diameters and their disclosed relationship to each other can be employed in all of the various disclosed embodiments of this invention.

Finally, although reference has been made to the yarns of the various disclosed embodiments having diameters, it is to be understood that the cross sectional shape of any or all of the yarns used in any of the embodiments may be of non-circular profile e.g. ovate, rectangular, square, bi-nodal, etc.